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EXPLOSIONS IN UTAH COAL MINES, 1900-1932

BY

D. J. PARKER

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INTRODUCTION

In attempting to discuss a subject of this character it should be clearly understood at the outset that the purpose is not to emphasize the mere fact of occurrence of such catastrophes, the memory of which time has largely relegated to oblivion, but rather to stress the means of their prevention, available not only subsequent to but also at the time of occurrence.

A careful, conscientious, unbiased study of the causes of mine explosions leads inevitably and definitely to the conclusion that the human element is the most important factor. The human factor should however, be evaluated in terms of responsibility--responsibility on the part of the employer to recognize the existing hazards and take the necessary remedial action, and on the part of the employee to perform his duties faithfully, diligently, scrupulously, and in strict conformity with State mining laws and company rules or other regulations.

While it is not the purpose of this report to endeavor to establish individual responsibility for any particular disaster it is important that the management accept the responsibility in nearly all instances for the prevention of such accidents.

The several causes of mine explosions in Utah will be discussed and analyzed, and definite recommendations will be made based on obvious conclusions drawn from the experience of the coal-mining industry, with a view to revitalizing the interest and concern prerequisite to the prevention of accidents as utterly unnecessary as mine explosions. The progress heretofore made in greater safety has been based largely on sad and costly experience, regardless of the type of industry involved.

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[1] The Bureau will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6752."

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HISTORICAL REVIEW[3]

The records of early exploration of Utah start with two Spanish priests--Escalante and Domingues, of Sandoval, N. Mex.--who reached the shores of what is now known as Utah Lake on September 23, 1776. Forty-eight years later, in 1824, Great Salt Lake was discovered by James Bridger, a trapper who came down the Bear River, and in 1832 a party under Captain Bonneville explored Salt Lake Valley.

If these early explorers discovered any coal, no record of the discovery has been preserved. On July 24, 1847, the first party of Mormon immigrants, led by Brigham Young, entered Salt Lake Valley and established the first permanent settlement. How soon after their arrival coal was discovered is difficult to ascertain. Marcus E. Jones, Treasury expert, reported to the Treasurer of the United States in 1890 that the first discovery of coal was made in Sanpete Valley and that in 1851 coal was discovered near Cedar City in the Colob-Kanab field.

Bulletin 285 of the United States Geological Survey says that coal was discovered at Wales, Sanpete County, in 1857 and mined in 1862; the 1896 report of the coal-mine inspector of Utah says that the Wales mine was the oldest coal mine in the State, having been opened in 1855, when the output was consumed by the surrounding settlements. It seems definitely established, therefore, that the Wales mine has the distinction of being the first worked. It is also known that the Winterquarters mine, opened in 1878, was the first in Carbon County. The Union Pacific Railroad was completed across Utah in 1869 and connected with Salt Lake by a branch line in 1870. The Wales mine was reached by rail in the early seventies. When Winterquarters was opened a narrow-gage railroad was accessible for shipping the coal to Provo.

FATALITIES

Table 1 lists 12 explosions, only 9 of which resulted in loss of life. The second and most disastrous explosion, also one of the worst in the mining history of the United States, with a loss of 200 lives, occurred May 1, 1900. The next in rank with respect to the number of lives involved (referred to as case 4) occurred on March 8, 1924, with a loss of 171 lives. Case 11 was the third highest, with a loss of 20 lives; cases 6 and 12 were next, with a loss of 5 lives each; cases 3, 5, and 10 accounted for two lives each; and case 8 one life. In cases 1, 7, and 9 no lives were lost because there were no men in the mine at the time.

Of the 9 explosions resulting in loss of life, 5 were major disasters, that is, those in which 5 or more persons were killed.

The total number of lives lost due to explosions in Utah from May 1, 1900 to July 1, 1933 was 408, and 90 percent of this total is due to the two largest explosions listed in table 1 as cases 2 and 4. From July 1, 1918 to June 30, 1933, inclusive, a period of 15 years, there were 528 fatalities in the coal mines of Utah from all causes, and 39 percent were killed by explosions.

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[3] Allen, C.A., Tech. Paper 345, 1925, 90 pp. Analyses of Utah Coals.

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From 1900 to 1932, inclusive, 110,282,580 tons of coal were produced; the number of tons produced per fatality from explosions alone was 270,300, and the number of fatalities from this cause per million tons mined was 3.6. Hence for this period the fatality rate from coal-mine explosions per million tons of production in Utah is higher than the average fatality rate of the coal mines of the United States for all causes of coal-mine accidents (falls, haulage, explosions, explosives, electricity, etc.).

Following the Winterquarters disaster on May 1, 1900, with its 200 fatalities, there was not a single major disaster due to explosions for almost 24 years. This is a rather remarkable record when it is considered that during this time practically no rock-dust was used, black powder was a common blasting agent in many of the mines for a number of years, blasting was done during the working shift in several mines, water was not very generously applied to cutter bars or roadways and face regions, nonpermissible electrical equipment was in more or less general use, and fireproof or fire-resistant stoppings were installed to only a limited extent. The immunity from explosions over at least the last 10 years of this period may be attributed largely to good fortune.

Since explosions do not happen by chance but from definite causes their prevention would likewise appear to be the result of well-directed effort; however, the rigid precautionary measures that were in effect for a number of years following the Winterquarters explosion tended to lull the industry into a false sense of security, and apparent relaxation of many safety practices and methods set in about the period of the World War.

CAUSES OF EXPLOSIONS

It is not always a simple matter to determine the exact cause--that is, the igniting agent--of an explosion; furthermore, frequently there are differences of opinion among mining men as to causation influences or agencies as found in investigations after such catastrophes. Some reasons for this are that those nearest the origin are often killed, the forces of the explosion tend to destroy the evidence, and not infrequently the initial explosion may be followed by one or more secondary explosions locally or even extending throughout the mine, thereby confusing the evidence of the cause of the first.

The data in table 1 on causes are based on such records as are available. The evidence, however, is not always conclusive; as a result, in some cases there may be divergency of opinion. It will be noted that 3 explosions, 2 covering the entire mine and 1 about half of the mine, resulted in neither injury nor fatality to anyone.

Of the 9 explosions resulting in 1 or more fatalities, 3 were caused by open lights, with 175 or 43.2 percent killed; 1 was caused by explosives (black blasting powder), with 200 or 49.4 percent killed; and 5 were caused by electricity, with 30 or 7.4 percent killed.

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Attention might be directed to the fact that 5 of the 12 explosions occurred in 2 mines, 2 in 1 mine and 3 in the other. Cases 4 and 7 refer to the same mine, and the other mine is designated by cases 5, 8, and 9. (See table 1.)

It would appear advantageous to group the 12 explosions by causes--that is, open lights, explosives and blasting, and electricity--and discuss briefly each case falling in its respective group.

OPEN LIGHTS

There is no known record of an explosion in Utah mines ever having been caused by matches or smoking material. Since the beginning of Statewide use of closed lights (permissible electric cap lamps) in mines of this State about the middle of 1924, no explosion or gas or dust ignition has been initiated by an open light, an improperly assembled flame safety lamp, or a defective permissible electric lamp.

The first five explosions of which there is record, covering the period from March 22, 1900, to May 23, 1924, were all in open-light mines, although permissible electric cap lamps were at hand at one mine but not yet installed when the explosion listed as case 4 occurred. These five explosions killed 375 men (92.6 percent of the total fatalities from explosions since 1900). Thirty men (7.4 percent of the total) have been killed by explosions since closed lights were introduced and in no instance was the closed light even remotely responsible for the ignition.

Case 3.--At the noon hour two men building a stopping proceeded into the air course, where it was warmer, to eat their lunch. A body of gas which had collected in a cavity in the roof was ignited by their open lights, and both men were fatally burned. The concussion was sufficient to blow out timbers, with resultant roof fall, which contributed further to the injury of the two men. This accident indicates poor ventilation and lack of proper gas inspection.

Case 4.--This explosion, which resulted in the death of 171 men (every man in the mine), was the second largest with respect to loss of life that has ever occurred in Utah; in fact, only 10 explosions have caused greater loss of life in coal mines of the United States.

There appeared to be enough evidence to establish the fact that this explosion originated in a room driven to the rise from an entry, the pitch of the coal bed being about 10 percent and thickness about 25 feet. The night before the explosion some of the top coal had been shot down in this room to within a few feet of the face. The fire boss was found on the inby side of this pile of top coal with his flame safety lamp, which had been disassembled. Two miners were found on the outby side of the coal pile close to a car of coal, which evidently had been loaded that morning. There is every indication that the fire boss had found gas near the roof in this room on his initial examination before the shift came into the mine and had gone back with the two miners to remove it--anything but safe procedure,

TABLE 1.- Gas and dust explosions in Utah coal mines, 1900-32

Case	Date	Mine	Type of mine	Tons per day	Possible means of prevention at time	Explosion			Causes of gas accumulation	Cause of ignition	Other factors	Men in mine		Killed	Injured	Escaped unassisted
						Type	Extent	Limited by				Average	At time of explosion			
1	Mar. 22, 1900	No. 1	Slope; open lights.	1,100	More care in blasting	Dust	Entire mine.	Not limited	- - - - - -	Blasting	Faulty detail in blasting practice.	325	0	0	0	0
2	May 1, 1900	Nos. 1 and 4	Drift; open lights.	- - -	Removal of dust, use of water, proper handling of explosives.	do	do	do	Explosive gas was never found in this mine.	Probably blasting.	Blasting with shift in mine.	312	312	200	7	No.4 – 2 No.1 – 103
3	Mar. 3, 1923	No. 3	Slope; open lights.	2,000	Proper gas inspection and supervision, closed lights.	Gas	Local	Probably dampness.	Cavity in roof.	Open light.	Faulty inspection and ventilation.	350	350	2	0	0
4	Mar. 8, 1924	No. 2	Drift; slope; open lights.	1,400	Rock-dust, water, good ventilation, and closed lights.	Gas and dust.	Entire mine.	Not limited	Faulty system of mining top coal.	Open light or flame safety lamp	Poor supervision, gas inspection, and ventilation.	171	171	171	0	0
5	May 23, 1924	No. 1	Slope; open lights.	2,000	Efficient ventilation, better supervision, closed lights.	Gas	Local	Wetted area	Poor ventilation	Open light.	Brushing gas with water from hose.	300	300	2	0	0
6	Sept. 21, 1924	do	Slope; closed lights.	1,000	Rock-dust, water, and good ventilation; permissible electrical equipment.	Gas and dust.	Entire mine.	Not limited	Lack of ventilation.	Electric mining machine	Fan had been shut down for repairs.	175	5	5	0	0
7	Aug. 8, 1928	No. 2	Drift; slope; closed lights.	2,500	Insufficient rock-dust, proper use of explosives.	Dust and probably gas	do	do	- - - - - - - -	Blasting	Faulty shooting practice.	130	0	0	0	0
8	Jan. 24, 1929	No. 1	Slope; closed lights.	2,000	Permissible locomotive, improved ventilation.	Gas	Local	Rock-dust and water.	Poor ventilation	Arc from locomotive controller.	Cavity in roof.	150	150	1	0	0
9	Jan. 25, 1929	do	do	2,000	Increased rock-dusting.	Dust and probably gas.	One half of mine.	Rock-dust barriers and water.	- - - - - - - -	Explosives	Probably poorly placed shot.	150	0	0	0	0
10	Jan. 20, 1930	No. 3	do	750	Permissible electrical equipment.	Gas	Local	Wet conditions.	Outrush of gas	Electric mining machine.	Nonpermissible mining machine.	100	Unknown	2	0	0
11	Feb. 6, 1930	Nos. 1 and 3.	Tunnel; slopes; closed lights.	1,100 600	Proper gas inspection, rock-dust, permissible electrical equipment.	Dust and gas.	Local in No. 1 violent in No. 3	Wet conditions in No. 1 and expansion.	Probably released by mining machine.	Sparks from machine bits or electric sparks or arcs.	Too infrequent gas inspection	166 43	26 3	No.1 – 17 No.3 – 3	2 -	7 -
12	Mar. 8, 1930	New	Slope; closed lights.	150	Good ventilation and supervision, permissible electrical equip.	Gas.	Local, little violence.	Wet conditions.	Fan down, insufficient natural ventilation.	Electric mining machine.	Poor supervision.	50	13	5	6	2
Total	- -	- -	- - -	- -	- - - - - - - - - - -	- - -	- - - -	- - - - -	- - - - - - - -	- - - -	- - - - - - -	- -	- - -	408	15	114

especially in an open-light mine. Evidently he had climbed on top of the coal pile which had been shot down the night before, and while he was testing for gas in the high place from which the top coal had fallen the flame on his flame safety lamp was extinguished by an explosive mixture of gas and air. After getting down from the pile of coal and apparently having used a spray of water from a hose to diffuse and partly remove from the high place the explosive gas accumulation the fire boss opened his flame safety lamp and was in the act of relighting it, using his carbide lamp, when he or one of the miners ignited the gas. The gas very probably was stirred up by the fire boss while making his test and while using the water spray. A roof fall, which occurred just before or at the time of the explosion and partly covered one of the miners, may have pulled the gas down to a point where it could easily have been ignited by one of the miners' carbide lamps; more probably, use of the water spray moved the gas so that it came in contact with an open light.

The first explosion apparently was initiated by a local gas ignition of sufficient magnitude to cause it to spread to adjacent places where there was much dust and possibly additional gas, and this precipitated a widespread, extremely violent, dust explosion. A few minutes after the first explosion a second occurred in which gas presumably played little or no part. While it was thought by many that a third explosion occurred, this was not substantiated by the evidence.

No rock dust had been used in this mine before the explosion, water being relied upon to render the coal dust nonexplosive. This occurrence emphasizes the fallacy of relying upon the use of water only as an agent to make Utah coal dust safe. Assuming that the unstinted use of water might serve to prevent fine coal from participating in an explosion, due to the human element involved, there would always be the probability of sufficient laxity to destroy in a large measure the reliability of this method of treating coal dust.

Permissible electric cap lamps had been delivered to the mine before the explosion but had not been put into service, pending arrival of part of the charging equipment; although the explosion might not have occurred if the electric cap lamps were being worn, on the other hand there is no guaranty that the fire boss might not have used a match to relight his flame safety lamp and thereby precipitated the disaster, as there was every evidence that he was attempting to relight the flame safety lamp when killed by the explosion.

This mine was one of the most safely equipped and operated in Utah; in fact, it was considered by many persons as a model mine with respect to safety. More than 180,000 cubic feet of air entered the mine every minute, and ventilation was by splits. The mine was considered one of the best-sprinkled properties in the State; sprinkling hose with adequate water pressure were maintained at each working face for use of those employed at or near the faces, and three full-time sprinklers were regularly employed to keep haulage roads and nonworking places dampened. However, certain parts of the mine, including that in which the explosion started, were very gassy, the coal dust is exceptionally explosive, the coal is of such nature as to give off much dust, the high coal worked on a pitch made effective ventilation difficult, the open lights and nonpermissible flame safety lamps were dangerous, and the procedure in removing an accumulation of explosive gas was anything but safe.

Case 5.--Two miners were fatally burned when they attempted to remove standing gas in their working place by "brushing" it out with water from hose, and the gas was ignited by naked lights in use in the mine. The place was "danger-marked", and the information is to the effect that the two miners, who were of foreign birth, had been warned to stay out of the place. It is possible that they did not fully understand the orders, as was brought out by some conflicting evidence. The explosion was local and was undoubtedly limited by the presence of moisture.

Substantially erected line canvas from the last open crosscut close to the face, well-maintained with a minimum of leakage, will under ordinary conditions keep the face free from gas accumulations. The proper time for removing standing gas is before the shift enters the mine, and then its removal should be attempted only by properly qualified persons taking all feasible precautions.

EXPLOSIVES AND BLASTING

Although there have been at least four explosions, presumably caused by explosives or blasting, only one resulted in loss of life. Since the introduction of permissible explosives, fired electrically, in Utah no mine explosion which resulted in a single fatality has been caused by blasting. Three explosions occurred at the time of blasting electrically from the surface with no one underground and no person was hurt on the surface or elsewhere: in 1 instance dynamite was used, and in 2 instances permissible explosives were employed. It is probable that in at least two cases the explosion was due to ignition of gas or dust or both by an electric arc rather than by the explosive.

Case 1.--When the explosion occurred this mine was one of the most progressive in the United States from a safety point of view; in his report to the Governor of Utah for 1899, the State mine inspector said of this property: "To guard against dust danger, the management has put in water and steam sprays to keep the mine damp."

"The coal is dug in the mine by being first undermined and shot off with Hercules powder, of which they used 38,450 pounds during the year 1899. All shots are fired by electricity, when all men are out of the mine, which I think is the safest way to mine coal where dust is explosive."

At about 7:30 on March 22, 1900, a shotfirer threw in the final shooting switch on the surface to put off all of the shots in the mine. He stated that the resultant concussion did not appear to be as loud or as strong as usual, so fearing that some shots had not "gone", he threw the electrical current into the shooting lines a second time. Immediately a very violent explosion occurred which blew out every masonry stopping and overcast in the mine, practically demolished about 200 mine cars, and in general wrecked the interior of the mine.

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The State mine inspector's report to the Governor on this explosion said: "The explosion was nothing more than a dust explosion caused by the firing of heavy shots on the ninth rise. ********* When the shots went off, they caused a great dust, and it is supposed caused some of the wires to become crossed, and when the current was turned on the second time, it caused a big flash and ignited the dust and caused the explosion."

While the property damage was heavy, no human being suffered any injury, an excellent tribute to the foresight of the mining company which before 1900 had in operation a system of blasting which was and is thoroughly effective in safeguarding human life in a mine known to have explosive gas and very inflammable dust.

Case 2.--According to the best available information, this explosion, which cost the lives of 200 men, originated in No. 1 mine but both No. 1 and No. 4 were involved. The explosion occurred about 10:25 A.M. on May 1, 1900. Seven were injured, 2 escaped from No. 4 mine and 103 from No. 1 mine, and about 84 employees of No. 4 mine and 116 from No. 1 mine were killed, the latter chiefly by gases.

The cause has never been absolutely determined. The theory has been advanced that firing shots in rotation raised a cloud of dust of sufficient intensity to permit ignition by subsequent shots, but the most probable theory appears to be that a quantity of black blasting powder was accidentally ignited by an open light, initiating the explosion, which was propagated by coal dust. Explosive gas is not known ever to have been found in either No. 1 or No. 4 mine from the time they were opened until they were finally worked out and abandoned, and there is absolutely no question that this was entirely a dust explosion.

When it is considered that mines at that time were operating with open lights, using black blasting powder, in many instances with several kegs in one working place, with shots stemmed with fine coal, and few if any limitations as to quantity of explosive per hole and firing done by miners with the shift in the mine, with absence of rock dust and little or no use of water to neutralize the coal dust, it is marvelous that there were not more disasters of this character.

The explosion in these two mines exemplified not only the hazard of open lights and black blasting powder in coal mines but was one of the most convincing instances of the explosibility of coal dust without the aid of explosive gas that had ever occurred and in fact that has occurred to this day. Moreover, it pointed out the hazard of connecting coal mines; in this instance, the explosion started in one mine, killed about 84 persons, and wrecked the mine; while the other mine was essentially unharmed by the explosion, the poisonous gases extended into the other mine and killed over 100 employees.

Case 7.--This explosion was essentially as violent as the one in this mine on March 8, 1924, although fortunately no lives were lost. The effects of the explosion extended to every part of the mine, wrecking concrete overcasts and blowing out nearly all the stoppings, which were also concrete.

Several fires resulted, which necessitated sealing a portion of the mine, and a local explosion occurred in the sealed area about the time the last seal was being completed, but with no damage to the seals and without injury to any workers.

The explosion occurred immediately after the closing of the master shot-firing switch on the surface. No one was in the mine at the time, and no one was injured on the surface.

There was much evidence of overcharged shot holes, and it is probable that explosive gas may have been present in one or more working faces. It appears to have been the custom to drill some shot holes to a depth of as much as 18 feet, slightly inclined upward to bring down top coal, and numerous shots of this type were fired in the same working places at one time. In view of such obviously unsafe practices in vogue before the explosion the occurrence was not wholly unanticipated by numerous well-informed mining men familiar with the conditions.

Although numerous questionable practices undoubtedly were employed with respect to blasting in this mine before this particular explosion, it is to the credit of the management that the system of blasting electrically from the surface with no one in the mine, which was adopted in this coal-mining community many years before, was in effect at the time of this explosion; therefore while the property loss was very heavy, no person was killed or injured.

Case 9.--This case also definitely proved the excellent safety policy of firing all shots from the surface with no one in the mine. The explosion occurred simultaneously with the closing of the master shot-firing switch on the surface. No one was injured, but considerable damage was done to that part of the mine traversed by the explosion wave. Concrete stoppings and overcasts were blown out; and many timbers were dislodged, followed by several heavy roof falls.

This mine is recognized as one of the most gassy in the State, and the coal dust is highly explosive. There was, however, no evidence of violence more than 3,000 feet in any direction from the origin of the explosion, and only about half the mine was affected. This affords one of the clearest-cut instances on record where a violent explosion was limited by rock-dust and rock-dust barriers plus wet zones.

The explosion originated in the face of an entry less than 200 feet long. A fire was started in this entry as a result of the explosion and was extinguished by local flooding. After the fire had been extinguished the entry was found to be caved to such an extent that it was never reopened. In consequence, evidence on the underlying cause of the explosion that might have been available at the face was lost.

The explosion may have been started by a misplaced shot, or gas may have been present as the result of a possible fall which may have brought down the line brattice between the time the shot holes were charged and the firing of the shots. Incidentally, this is one of the best-supervised mines in the State, as evidenced by operating the up-to-date shot-firing system, the unremitting effort to maintain good ventilation, and numerous other practices and installations in line with safe mining practice in a property with numerous inherent hazards.

ELECTRICITY

Although electricity has become a most important economic factor in the production of coal, on the other hand its wide, varied, and extensive application has created one of the greatest hazards in modern coal mining.

Electricity was either directly or indirectly responsible for 5 of the 12 explosions. Four of the five were fairly clean-cut cases, but in the fifth there was the possibility that gas was ignited from sparks caused by mining-machine bits cutting against a rock spar, not an uncommon occurrence in that section of the mine.

Electricity accounts for starting 45 percent of the explosions that have occurred in Utah. Thirty-three fatalities (8.0 percent of the total number (408) killed by explosions in the coal mines of Utah) were due to ignitions by electricity.

It will be noted from table 1 that 4 of the 5 explosions of electrical origin were caused by electric coal-cutting machines (nonpermissible type) and the other by an electric (trolley-reel type) locomotive.

Case 6.--This explosion occurred about 6:00 p.m., with only five men in the mine, all of whom were killed. A few minutes later a second explosion occurred, the cause of which was never satisfactorily determined. The initial explosion was comparatively light, while the second explosion was violent, covering all parts of the mine. As an indication of the high pressures developed, a 5- by 6-foot timbered intake-air shaft, 50 feet deep, was increased to about 8 by 10 feet in cross section, all of the timber and loose rock between the timber and the solid rock being scattered along the surface adjacent to the shaft collar.

This was a closed-light mine, permissible electric cap lamps being used by the underground force. Magnetically locked permissible flame safety lamps were used for gas testing.

The mine had been partly rock-dusted which, as in other instances, may have given a false sense of security.

The evidence indicated fairly conclusively that a body of standing gas was ignited by sparks or arcs from a mining machine. It was stated that on the day of the explosion a curtain had been placed across the slope, which was one of the two intakes, to deflect the air into a section of the mine which was being rock-dusted. Assuming this to be true, that section of the

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mine in which the explosion is supposed to have originated would be deprived, for the time being, of the proper amount of air. It was further stated that at the time of the explosion the fan had been shut down for emergency repairs.

This mine was classed as gassy, and either of the above incidents might account for the presence of standing gas.

Case 8.--A motorman was fatally burned by a local gas explosion while pushing four empty cars into a slant or inclined crosscut with a trolley-reel locomotive operating from the trailing cable. The locomotive had reached a knuckle in the slant crosscut, and a roof cavity over this point was apparently filled with gas. The movement of the cars probably brought the gas down to a level with the controller.

Proper inspection and subsequent removal of the gas, or the use of a permissible storage-battery locomotive, would have prevented the accident. A dust explosion, possibly extending throughout the mine, was prevented by rock-dust and damp to wet conditions at the point of origin.

Case 10.--A machine runner and his helper, after cutting a place, had loaded the machine on the truck when a local gas explosion caused their death. This place had been inspected by the fire boss 3½ hours before it was cut and found clear of gas. The line brattice extended to within 6½ feet of the face. The nonpermissible machine had evidently cut into a "blower" which filled the face region with gas. The gas was ignited by an electric arc or spark or from an overheated resistance. The explosion, which was of sufficient violence to blow the nips of the trailing cable off the power circuit, was limited by the naturally wet conditions which extended 120 feet back from the face.

Case 11.--The explosion originated in No. 3 mine and extended through a rock tunnel, 2400 feet in length, into No. 1 mine. Three men were in No. 3 mine and 26 in No. 1 mine; this constituted the entire night shift of both mines. All in No. 3 mine were killed and 17 in No. 1 mine.

In No. 3 the explosion was violent and covered virtually the entire mine. Little violence was manifested in No. 1 mine, only two of the 17 being killed by violence. The rock tunnel connecting the two mines was naturally wet to such an extent that no flame reached No. 1 mine; 15 of the 17 perished from the effects of the afterdamp in this mine. Both mines had been partly rock-dusted; this again illustrates the futility of relying on "half-way" explosion-prevention measures.

The last inspection for gas in the place in which the explosion is supposed to have originated was made about 15 hours before the machinemen began cutting the place. There were two mining machines, both of nonpermissible type, in operation at the time of the explosion. One was traveling outby in a room, while the other was undercutting in another section of the mine.

A body of gas was ignited by one of the two machines or possibly by a spark caused by machine bits cutting a rock spar. The gas may have been released by the undercutting. There is also a possibility that 1 of 3 doors may have been left open, thereby short-circuiting the air.

Case 12.--Of the 13 men in the mine at the time of the explosion, 5 were killed, 6 were injured, and 2 escaped uninjured.

The mine was in the initial stages of development and was recognized as extremely gassy. In spite of this fact the fan was not in operation at the time of the explosion, neither was line brattice used to ventilate the faces, 3/4-inch compressed air lines being relied upon to give the necessary face ventilation.

The evidence, while perhaps not absolutely conclusive, indicated beyond a reasonable doubt that the explosion was caused by ignition of gas by a nonpermissible electric mining machine. The evidence further indicated that this was a gas explosion in which coal dust played a minor part, due to the limited extent of the mine workings and the liberal use of water on cutter bars and the face regions. No rock-dusting had been done up to the time of the explosion. The mine was on a strictly closed-light basis, but the nonsmoking rule was inforced with laxity if at all.

This explosion illustrates the folly of trying to operate a gassy mine without enough face ventilation and with nonpermissible electrical equipment and is another instance of the danger of trying to move explosive gas or to ventilate gassy regions by a jet of compressed air or of water.

PREVENTION OF EXPLOSIONS IN UTAH COAL MINES

A review of the foregoing occurrences is of value only in so far as it may impress upon the industry the possibility of the recurrence of explosions and to emphasize the lessons to be learned from those which have already happened. Of greater importance, however, is application of the knowledge gained through scientific research relative to the methods of preventing explosions.

Of all accidents occurring in coal mines there appears to be least justification for those resulting from mine explosions. The United States Bureau of Mines, through large-scale tests at its Experimental mine, has proved that dust from Utah coals ranks among the most explosive in the country. Through such tests it was determined that at least 70 percent of incombustible material must be present to prevent propagation of an explosion by Utah coal dust when explosive gas is absent.

Rock-dusting; rock-dust barriers; water applied generously to cutter bars, face regions, coal piles, empty and loaded cars, and haulage roadways; adequate ventilation; rigid fire-boss inspection, with accurate daily reports; permissible explosives, used in a permissible manner; permissible electrical equipment, properly maintained; closed lights, of permissible type; permissible flame safety lamps; tight cars; clean tracks; limited topping of cars; enforcement of the no-smoking rule, plus good supervision--all of which are within

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the reach of the average mine operator--will go far toward preventing dust explosions and reduce the likelihood of gas ignitions to a remote possibility.

ROCK-DUST

Experiments in the use of incombustible dust or rock-dust to reduce the coal-dust hazard in mines were conducted in Great Britain and France as far back as 1906 and 1907, and the United States Bureau of Mines determined in 1913 the effectiveness of rock-dusting and so stated in its publications.

It required many years of intensive educational work to convince the bituminous-coal-mining industry that coal dust in the absence of inflammable gas is explosive. For more than 20 years the Bureau of Mines has endeavored to gain general recognition of the fact that rock-dust properly applied in connection with coal dust would prevent the propagation of coal-dust explosions, yet at this time not one percent of the coal mines of the United States are effectively protected by rock-dusting.

> To prevent the propagation of mine explosions, the Bureau of Mines recommends[4] rock-dusting in all coal mines, except anthracite mines, in every accessible part, whether in damp or dry condition. It also recommends that rock-dust barriers be used to sectionalize the mine as additional defense; but they should not be regarded as a substitute for generalized rock-dusting.
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> Rock-dusting methods are based upon the facts (1) that coal dust when mixed with sufficient incombustible dust will not explode, burn, or assist in propagating an explosion, and (2) that dry, fine, incombustible dust raised into the air in a sufficiently dense cloud will tend to check and stop a coal-dust explosion. These facts have been demonstrated by many experimental tests in this country and in Europe, and after both local and general explosions in operating mines.
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> Rock-dusting a mine is likely to be of little or no value in preventing the propagation of an explosion unless it is thoroughly done and well maintained. Rock-dusting insufficiently done leaves a false sense of security, if gas or dust is ignited and an explosion started, which continues along undusted aircourses or poorly dusted entries, emphasis is likely to be placed upon the "failure" of rock-dusting rather than upon the insufficient dusting.
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> The first step in the adequate rock-dusting of a mine should be thorough cleaning by washing down of all passageways and loading out of as much loose and gobbed material as practical. Rock-dusting should be started in the sections of a mine where explosions would be most likely to start, such as dry sections liberating considerable gas. Producing entries should generally be the first entries dusted. A mine should be

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[4] U. S. Bureau of Mines Accident Prevention Course, Section 2, Explosion and Fire Prevention

rock-dusted from the face outby, and rock-dusting advanced as the workings advance. All crosscuts, rooms, pillar workings, and entries should be dusted within at least 40 feet of the face or to the last breakthrough. A commendable practice, rapidly coming into use, is to keep the rock dust within three cuts of the working face. All entries or workings from which track is to be removed, should receive a heavy coating of rock dust on ribs, roof, and floor before track is removed. Aircourses and other places having no track may be dusted by means of tubing carried from a rock-dusting machine through doors or holes in stoppings and along the aircourse to be dusted. There are machines on the market capable of blowing dust through several hundred feet of tubing. Good rock-dusting may be done either by hand or machine. Hand dusting of aircourses has been done by men applying dust from bags hung on their shoulders and transporting sacks of dust through the aircourses by sled. Another method used is to blow dust through stoppings into aircourses at intervals of 200 to 400 feet. If there is a good velocity of air in such aircourses, fine dust will carry well; if there is little air traveling, the rock-dusting done in this manner will be poor except near the points of dust discharge.

The amount of dust to be applied to an entry depends on the character of the coal, the amount of incombustible matter already present in the mine road, and rib dust, as well as the practices likely to cause deposition of coal dust day by day. In medium and high-volatile coals enough rock dust should be added to the rib, roof, and floor surfaces so that the road dust and the rib and roof dust, considered separately, each contain over 65 percent (not less than 70 percent for Utah coals) incombustible material. There should be enough additional dust added so that there will be a safety factor, that is, so that redusting will not be immediately necessary. Usually 3 to 4 pounds of rock dust per linear foot of entry is the minimum to apply on first dusting. Redusting, particularly of haulage entries, may be necessary at frequent intervals if there is much coal spillage or if there is much coal dust thrown into the air current by rapidly moving trips.

The best practical means of determining whether rock-dusting is sufficient is by sampling the mine dust and testing the samples for incombustible content. This should be done after rock-dusting and at frequent and regular intervals thereafter. After some experience has been gained in rock-dusting, one can judge to a considerable extent by eye as to the more poorly dusted places and take samples accordingly, although samples collected at definite points determined without reference to condition of the dust will probably give a truer picture of dust conditions in the mine.

The quantity of coal dust which a silver quarter-dollar will hold is the minimum amount per cubic foot of air that will explode. It is believed that this fact is not generally appreciated and it is readily apparent that very few coal mine workings have fine dust content as low as this very small amount, hence practically all parts of coal mines have the hazard of explosive dust.

EFFECT OF WATER ON EXPLOSIBILITY OF COAL DUST

Wet dusts can not be classified with dry dusts because of the tendency of the particles to cling together, making the formation of a dust cloud more difficult. Experiments have shown[5] that the effectiveness of water in preventing scattering of dust is the only thing that can justify its use; at the working face there is certainly ample place for it. On the other hand, the use of water to render coal dust nonexplosive in mine passageways has been a flat failure, and there is experimental evidence to show that it can not succeed with bituminous coals. Tests were made in 1925 of mixtures of four Utah coal dusts and water. It was found in the course of this investigation that 20 percent water was as much as these dusts (size 20 percent through 200-mesh) would retain; if more was added, it sank through the dust and drained away, confirming in general earlier similar tests on Pittsburgh bed coal dust. Mixtures of two of the coals containing 20 percent water propagated explosions under standard propagation test conditions. A similar mixture of the third coal was subjected to a gas explosion and also propagated flame throughout the test zone. These tests leave little doubt concerning the explosibility of wet bituminous coal dusts. It is true that such wet dusts are raised into the air from the floor only with considerable difficulty, but they are dislodged from higher surfaces or timbers with ease, and when formed in a cloud by any means, they ignite and propagate flame despite the presence of the water.

There have been a number of disastrous explosions in supposedly well-watered mines, and even where water has collected in a low place or "swamp" for distances of 100 to 200 feet, an explosion flame has jumped over it, and has even coked dust floating on top of the water.

CONCLUSIONS

Mine explosions can be prevented by applying practices and methods now readily understood and available. They will be prevented only when there is firm determination on the part of the management to do so.

The three primary causes of the explosions described in this paper were explosives and blasting, open lights, and electricity. Only one of the four explosions chargeable to explosives and blasting resulted in loss of life; the other three resulting in no loss of life, are notable instances of the advantages to be derived from blasting with no one underground. The one explosion in Utah's coal mines with blasting as the cause and the loss of life occurred in 1900 when black blasting powder, open lights and blasting during the shift were allowed; all of these are now outlawed and it is significant that in mines with the unusual inherent hazards such as afflict the coal mines of Utah not a life has been lost in a Utah coal mine through an explosion caused by blasting, since blasting during the working shift has been prohibited.

The almost universal adoption of the closed light in the coal mines of Utah was a tremendous step in the right direction. At least 175 persons have been killed in the coal mines of Utah through ignitions by open lights, but

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[5] U. S. Bureau of Mines Accident Prevention Course, Section 2, Explosion and Fire Prevention.

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not a single life has been lost through the use of the permissible electric cap lamp. Some of the smaller or "wagon" mines are now using the open light, and sooner or later fatalities are almost certain to occur by fires, explosions, or other untoward occurrence brought about by open lights.

Four at least (if not all) of the explosions attributable to electricity probably would not have occurred had permissible equipment been in use at the time. Through the cooperation and foresight of the Industrial Commission and the Mine Inspection Department, permissible electrical equipment for use at the working face is being more generally adopted, and for the well-being of all concerned in Utah coal mines it is hoped that within a relatively short period of time all devices and equipment used therein will be of permissible types.

It is confidently believed that with a responsive industry, effective inspection, close supervision, rigid discipline, and safety education of the workers, explosions in the coal mines of Utah will be greatly reduced if not wholly eliminated, notwithstanding the fact that up to the present the fatality rate in Utah coal mines from explosions is the poorest of the States that produce coal.